

1 TITLE

2

3 "Detector Assemblies and Methods"

4

5 FIELD OF THE INVENTION

6

7 This invention relates to detector assemblies for
8 use principally, but not exclusively, in well
9 logging.

10

11 BACKGROUND OF THE INVENTION

12

13 The latest hydrocarbon production methods require
14 that the production section of the well has a
15 maximum possible length in the oil-bearing stratum.
16 Since most oil-bearing production zones are
17 substantially horizontal, this results in the final
18 section of the well becoming appropriately
19 horizontal. Although the general location of an
20 oil-bearing stratum may be known prior to the
21 drilling of a production well to tap the oil-bearing
22 stratum, the position (in all dimensions) of the

1 production zone is not initially known with
2 sufficient accuracy to ensure that the well can be
3 bored directly to the production zone. Accordingly,
4 geological formation data are collected as the well
5 is drilled, and the collected data are suitably
6 analysed to derive the exact direction (in all three
7 dimensions) along which the well is to be extended,
8 particularly to ensure that the final (and usually
9 horizontal) section of the well is in the best
10 position for the recovery of oil. The procedure is
11 known as "geosteering".

12
13 Geological formation data are commonly gathered by
14 gamma logging, i.e. by a procedure in which the
15 intensity of detected gamma radiation is utilised to
16 deduce geological properties. (While the source of
17 gamma radiation may be naturally occurring
18 radioisotopes more or less distributed throughout
19 surrounding geological formations, a more usual
20 source of gamma radiation is a manufactured gamma
21 source (e.g., a compact mass of cobalt-60) emplaced
22 at a fixed or controllably variable depth in an
23 adjacent well such that the gamma source radiators
24 through the geological formations between the gamma
25 source radiates through the geological formations
26 between the gamma source and a gamma detector in the
27 production well being drilled).

28
29 In order to geosteer, directional logging is
30 necessary. For example, the intensity of detected
31 gamma radiation above the bore of the well being
32 drilled may be compared with the intensity of

1 detected gamma radiation below the bore in order to
2 decide the direction and extent by which to deviate
3 the inclination of the next section of well to be
4 drilled.

5
6 A gamma radiation detector typically comprises an
7 assembly of a gamma-sensitive crystal (which emits a
8 visible photon in response to the impact of a gamma
9 photon), a photomultiplier (which outputs an
10 electrical pulse count proportional to the light
11 output of the gamma-sensitive crystal which, in
12 turn, is proportional to the intensity of incident
13 gamma radiation), and a pulse counter to accumulate
14 a count, over a fixed interval, of electrical pulses
15 from the photomultiplier.

16
17 The gamma radiation detector can be made
18 directionally sensitive by surrounding the gamma-
19 sensitive crystal with a gamma radiation shield
20 (e.g., a tungsten shroud), the shield having an
21 aperture or window through which gamma radiation can
22 reach the gamma-sensitive crystal but only from one
23 direction.

24
25 In order to carry out directional gamma logging of
26 the well, it is necessary to orient the shield
27 window to a selected angle with respect to a
28 notional vertical plane through the well bore, and
29 obtain a series of gamma intensity readings at
30 various such angles, thereby to obtain a polar
31 survey of geological formations surrounding the
32 location of the detector.

1 In prior art well-drilling operations, the gamma
2 radiation detector was incorporated into a bottom-
3 hole drilling assembly. Directional gamma logging
4 required that normal rotation of the drill string
5 had to be stopped, and the drill string manipulated
6 to orient the window to the required series of
7 angles. The prior art directional logging procedure
8 was therefore time-consuming, and prevented drilling
9 during logging. (Transmission to the surface of
10 logging data was also time-consuming, being usually
11 undertaken by inducing pressure pulses in the
12 drilling mud).

13
14 There is therefore a requirement for a means of
15 conducting well logging operations such as gamma
16 logging during drilling.

17
18 As will be discussed below, gamma logging during
19 drilling requires the establishment of the angular
20 orientation of a downhole assembly about the
21 borehole axis. There are other situations in which
22 knowledge of this angular orientation is desirable,
23 for example in operation of the controllable
24 stabiliser described in EP-A-1024245. The present
25 invention aims to provide a convenient means of
26 doing so.

27

28 SUMMARY OF THE INVENTION

29

30 According to one aspect of the present invention,
31 there is provided a rotary assembly comprising a
32 rotatable shaft; a sleeve journaled on the shaft

1 and adapted to be stationary during rotation of the
2 shaft; an earth vector sensor mounted for rotation
3 with the shaft, the earth vector sensor being
4 responsive to a given physical parameter in a
5 direction substantially radial to the shaft; and an
6 orientation signal generator which comprises means
7 for generating a pulse train representing rotation
8 of the shaft relative to the sleeve as a
9 predetermined number of pulses per revolution, and
10 means for deriving from the pulse train and the
11 output of the earth vector sensor the angle between
12 the earth vector and a given position on the sleeve.

13
14 Preferably, the rotary assembly is a downhole
15 assembly adapted to form part of a drill string, and
16 the earth vector is the component transverse to the
17 drill string axis in the vicinity of the assembly of
18 the earth's local magnetic field or gravitational
19 field.

20
21 The means for generating a pulse train preferably
22 comprises a directional sensor arranged radially of
23 the shaft and cooperating with a plurality of
24 elements equispaced around the circumference of the
25 sleeve. In a preferred embodiment, said elements
26 are ferromagnetic segments, and the sensor is a
27 coil; the ferromagnetic elements may suitably be 24
28 in number.

29
30 Said deriving means preferably operates to integrate
31 the earth vector sensor output over each of a number
32 of successive part-revolutions, for example quarter

1 revolutions, of the shaft to provide a series of
2 simultaneous equations, and solving these equations
3 to provide an orientation angle for each of said
4 plurality of elements with respect to the earth
5 vector.

6
7 From another aspect, the invention provides a method
8 of sensing the angular position of a rotary assembly
9 which comprises a rotatable shaft and a sleeve
10 journaled on the shaft and adapted to be stationary
11 during rotation of the shaft; the method comprising
12 sensing an earth vector along an axis transverse to
13 and rotating with the shaft, generating a pulse
14 train representing rotation of the shaft relative to
15 the sleeve as a predetermined number of pulses per
16 revolution, and deriving from the pulse train and
17 the earth vector the angle between the earth vector
18 and a given position on the sleeve

19
20 DESCRIPTION OF PREFERRED EMBODIMENT

21
22 One embodiment of the first aspect of the invention
23 will now be described, by way of example, with
24 reference to the accompanying drawings, in which:

25
26 Fig. 1 is a schematic cross-section of
27 part of a downhole rotary assembly; and
28 Fig. 2 shows a pulse train produced in the
29 assembly of Fig. 1.

30
31 Referring to Fig. 1, a shaft 10 forms part of a
32 downhole assembly. A sleeve 12 is rotatable with

1 respect to the shaft 10. In use, the sleeve 12
2 engages with a well bore and is rotationally
3 stationary, with the shaft 10 rotating within it.

4
5 The assembly determines orientation by reference to
6 an earth vector E, which is that component of the
7 local earth magnetic field or local earth gravity
8 acting at right angles to the shaft axis.

9
10 The assembly includes an earth vector sensor 14
11 mounted on the shaft for rotation therewith. The
12 earth vector sensor 14 is a sensor for measuring the
13 amplitude of the earth magnetic field or gravity
14 along a rotating axis OX radial to the shaft.

15
16 The sleeve 12 is provided with a number (in this
17 embodiment twenty four) of equally circumferentially
18 spaced ferromagnetic segments 16, which cooperate
19 with a pick-off coil 18 mounted on the shaft 10.
20 The pick-off coil 18 is arranged, in this
21 embodiment, to detect along the same axis OX as the
22 vector sensor 14 but could be arranged on a
23 different radius of the shaft 10 as long as the
24 angle between the two detector axes is known.

25
26 The pick-off coil 18 produces a pulse train P0 - P24
27 as illustrated in Fig. 2. The outputs of the earth
28 vector sensor 14 and the pick-off coil 18 are
29 processed as will now be discussed. It will be
30 apparent to those in the art that the signal
31 processing to be described can be effected by
32 readily available electronic circuits or computers.

1 EARTH VECTOR SENSOR OUTPUT

2

3 If the (constant) angular velocity of the rotating
4 shaft is W then

$$5 \quad W = d(S)/dt$$

6

7 If time = 0 when (OX) is aligned with the Earth
8 Vector Reference Direction (OE), then the Shaft
9 Orientation Angle at any subsequent time t is given
10 by

11

$$12 \quad t$$

$$13 \quad S = \int_0^t W \cdot dt = W \cdot t$$

14 0

15 and the Segment n Orientation Angle

$$16 \quad S_n = W \cdot t_n$$

17

18

19 If the period of rotation of the drill sting is T
20 then

$$21 \quad T = 2\pi/W$$

22

23 With reference to Figure 1, the magnitude of the
24 sensed vector along the sensing axis direction (OX)
25 at time t can be written as

26

$$27 \quad E_x(t) = E \cdot \cos(W(t)) + E_k$$

28

29 where E is the magnitude of the Earth Reference
30 Vector $\{E\}$ and E_k is a constant term provided that W
31 is constant.

32

1 Thus, the sensing transducer output at time t can be
 2 written as

$$3 \quad V_x(t) = V \cdot \cos(W \cdot t) + V_k$$

5
 6 where V_k is a constant term combining the transducer
 7 bias and the term E_k . $V = SF \cdot E$ where SF is the
 8 transducer scale factor (volts/g).

9 10 **EARTH VECTOR SENSOR OUTPUT INTEGRATIONS**

11
 12 If Pulse P_0 of figure 1 is an arbitrarily chosen
 13 pulse at some time t_0 the repeated pulses P_0 , P_6 , P_{12}
 14 and P_{18} associated with times t_0 , $t_0 + T/4$, $t_0 + T/2$,
 15 $t_0 + 3T/4$ respectively are used to control the
 16 integration of the sensing transducer output $V_x(t)$
 17 over 4 successive quarter periods of rotation
 18 starting at time t_0 .

19
 20 Consider the Integration of $V_x(t)$ from any initial
 21 time t_i to $t_i + T/4$

$$Q = \int_{t_i}^{t_i + T/4} v \cdot \cos(\omega \cdot t) \cdot dt + \int_{t_i}^{t_i + T/4} v k \cdot dt$$

5 Thus,

```

6                                     ti+T/4
7      Q = [ (V/W) . sin(W.t) ]      + V.k.T/4
8                                     ti

```

10 or

$$11 \quad Q = (V/W) \cdot [\sin(W \cdot t_i + W \cdot T/4) - \sin(W \cdot t_i)] + K$$

12 or

$$13 \quad Q = (V/W) \cdot [\sin(W \cdot t_i + \pi/2) - \sin(W \cdot t_i)] + K$$

14 or

$$15 \quad Q = (V/W) \cdot [\cos(W.t_i) - \sin(W.t_i)] + K \quad \dots\dots\dots (i)$$

16 Where K is a constant = $V_k.T/4$

17

18 Using equation (i), the integration of $V_x(t)$ from

19 time t_0 to time $t_0+T/4$ yields

$$20 \quad Q_1 = (V/W) \cdot [\cos(W.t_0) - \sin(W.t_0)] + K \quad \dots\dots\dots(ii)$$

21

22 Using equation (i), the integration of $V_x(t)$ from

23 time $t_0 + T/4$ to time $t_0 + T/2$ yields

24

$$Q2 = (V/W) \cdot [\cos(W.t_0 + W.T/4)] - \sin(W.t_0 + W.T/4)] + K$$

26

27 or

28

29 $Q2 = (V/W) \cdot [\cos(W.t_0 + \pi/2) - \sin(W.t_0 + \pi/2)] + K$

30

31 or

32

$$Q2 = (V/W) \cdot [-\sin(W.t_0) - \cos(W.t_0)] + K \quad \text{..... (iii)}$$

2

3 Using equation (i), the integration of $V_x(t)$ from
4 time $t_0 + T/2$ to time $t_0 + 3T/4$ yields

5

$$Q3 = (V/W) \cdot [\cos(W.t_0 + W.T/2) - \sin(W.t_0 + W.T/2)] + K$$

7

8 or

9

$$Q3 = (V/W) \cdot [\cos(W.t_0 + \pi) - \sin(W.t_0 + \pi)] + K$$

11

12 or

13

$$Q3 = (V/W) \cdot [-\cos(W.t_0) + \sin(W.t_0)] + K \quad \text{..... (iv)}$$

15

16 Using equation (i), the integration of $V_x(t)$ from
17 time $t_0 + 3T/4$ to time $t_0 + T$ yields

18

$$Q4 = (V/W) \cdot [\cos(W.t_0 + W.3T/4) - \sin(W.t_0 + W.3T/4)] + K$$

20

21 or

22

$$Q4 = (V/W) \cdot [\cos(W.t_0 + 3\pi/2) - \sin(W.t_0 + 3\pi/2)] + K$$

24

25 or

26

$$Q4 = (V/W) \cdot [\sin(W.t_0) + \cos(W.t_0)] + K \quad \text{..... (v)}$$

28

29 Writing $K1 = V/W$ and $\alpha = W.t_0$ then equations (ii)
30 through (v) yield for the four successive
31 integrations of $V_x(t)$

32

$$1 \quad Q1 = -K1.\sin \alpha \quad + \quad K1.\cos \alpha \quad +K \quad \dots\dots(vi)$$

$$2 \quad Q2 = -K1.\sin \alpha \quad - \quad K1.\cos \alpha \quad +K \quad \dots\dots(vii)$$

$$3 \quad Q3 = K1.\sin \alpha \quad - \quad K1.\cos \alpha \quad +K \quad \dots\dots(viii)$$

$$4 \quad Q4 = K1.\sin \alpha \quad + \quad K1.\cos \alpha \quad +K \quad \dots\dots(ix)$$

5

6 ROTATION ANGLES

7

8 Equations (vi) through (ix) can be solved to yield
9 angle α ; there is a degree of redundancy in the
10 possible solutions but, for example,

11

$$12 \quad Q1 - Q2 = 2K1.\cos \alpha$$

13

14 and

15

$$16 \quad Q3 - Q2 = 2K1.\cos \alpha$$

17

18 or

19

$$20 \quad \sin \alpha / \cos \alpha = (Q3 - Q2) / (Q1 - Q2) \quad \dots\dots\dots(x)$$

21

22 Since $\alpha = W.t_0$ then α is the angle S_0 between (OE)
23 and the radius through the segment which activates
24 pulse P_0 , or the angle between (OX) and (OE) at the
25 time t_0 when P_0 occurs, it follows that when Pulse P_n
26 occurs at time t_n the angle between (OX) and (OE) is

27

$$28 \quad S_n = \alpha + n.2\pi/24 \quad \dots\dots\dots(xi)$$

29

30 Thus, the segment orientation angles S_n for each
31 segment are known and the corresponding pulses can

1 be used to control events at known 15 degree ($2\pi/24$)
2 rotating shaft orientation angles.

3
4 The foregoing embodiment may be incorporated in a
5 controllable stabiliser apparatus as described in
6 EP-A-1024245 to provide an orientation reference.
7 In such use, the embodiment described may have an
8 additional function. In EP-A-1024245 a controlled
9 eccentricity is produced between the shaft 10 and
10 the sleeve 12. By examining not only the timing but
11 also the amplitude of the pulses P0 - P24, the
12 amount of eccentricity at any time can be
13 determined.

14
15 The present invention in another aspect provides a
16 well-logging procedure comprising the steps of
17 providing a directional well-logging means in a
18 bottom-hole assembly, the directionality of the
19 logging means being substantially synchronous with
20 rotation of the bottom-hole assembly, providing
21 direction sensing means in the bottom-hole assembly
22 for sensing the instantaneous direction of the
23 bottom-hole assembly and hence of the well-logging
24 means, providing a respective logging data reception
25 means for each direction for which well logging is
26 to take place, and switching the output of the well-
27 logging means between appropriate ones of the
28 logging data reception means according to the
29 instantaneously sensed direction of the bottom-hole
30 assembly whereby to accumulate directional logging
31 data during rotation of the bottom-hole assembly.

32

1 The well-logging procedure may comprise the further
2 step of subsequently transmitting accumulated
3 directional logging data to the surface by utilising
4 a data transmission means that does not require
5 cessation of rotation of the bottom-hole assembly.

6
7 The invention in this further aspect may also be
8 defined in terms of well-logging equipment
9 comprising a rotatable bottom-hole assembly
10 including a directional well-logging means whose
11 directionality is substantially synchronous with
12 rotation of the bottom-hole assembly, direction
13 sensing means for sensing the instantaneous
14 direction of the bottom-hole assembly and hence of
15 the well-logging means, a respective logging data
16 reception means for each direction for which well
17 logging is to take place, and switching means for
18 switching the output of the well-logging means
19 between appropriate ones of the logging data
20 reception means according to the instantaneously
21 sensed direction of the bottom-hole assembly.

22
23 The bottom-hole assembly may further comprise data
24 transmission means capable of selectively
25 transmitting accumulated directional logging data to
26 the surface, the data transmission means preferably
27 not requiring cessation of rotation of the bottom-
28 hole assembly.

29
30 The directional well-logging means may comprise a
31 directionally sensitive gamma logger which is
32 mounted within the bottom-hole assembly and is

